Appendix A.
PE-LOS and Mitigation Measure Assessment

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Technical Memorandum
Water Supply Forum – Regional Resiliency Project

To:	Andrew Graham, HDR Project Manager
From:	Don Ballantyne, Ballantyne Consulting LLC
Date:	July 26, 2018
Subject:	PE-LOS and Mitigation Measure Assessment (Task 106)

1.0 Scope of Work

This Technical Memorandum summarizes results of the Initial Phase of Task 106, Post -Earthquake Level of Service performance goals (PE-LOS). The task is limited to PE-LOS development for supplies, transmission/terminal reservoirs, and service to essential facilities, but excludes distribution system pipe and facilities. The task considers a range of PE-LOS goals and associated mitigation measures and the cost of the associated mitigation measures. Costs are developed by the participating utilities.

Development of the PE-LOS goals was performed working with Everett, Seattle (Seattle Public Utilities, [SPU]), Tacoma (Tacoma Public Utilities [TPU]), and the Cascade Water Alliance (CWA). Ultimately the CWA chose to be part of the SPU PE-LOS goals, as SPU provides CWA's water supply.

Mitigation measures were considered for three levels of PE-LOS goals: basic, moderate, and aggressive. In the Initial Phase, PE-LOS goal tables were developed as follows:

- Individually for 3 utilities (SPU and CWA combined) – Cascadia Subduction Zone (CSZ) and crustal scenarios, 50-year planning horizon, aggressive mitigation (2 PE-LOS table for each of 3 utilities.
- Regional - CSZ and crustal scenarios, 50-year planning horizon, aggressive mitigation (2 Events PE-LOS Table) that would be proposed to represent a regional minimum PE-LOS.

Additional tables for basic and moderate mitigation programs and for a 20-year planning horizon can be developed after discussion of the initial tables.

2.0 Introduction

PE-LOS performance goals are intended to provide guidance in design of new and upgrade of existing facilities particularly in the development of the Capital Improvement Plan (CIP), and planning for emergency response and recovery. They are not intended to be standards or code requirements to which a utility must adhere.

Development Process

PE-LOS goals have been developed considering a range of inputs:

- Community needs as identified by the utilities
- Goals developed by other water utilities
- Goals suggested in guidance documents
- Expected performance of existing systems (developed in Phase 1 of this Water Supply Forum project, and internally within each utility).
- High level cost to upgrade to meet those goals

PE-LOS formats used by others were reviewed and discussed at a Water Supply Forum workshop. The PE-LOS format was agreed on as presented later in this technical memorandum (TM). Each of the three utilities then took the PE-LOS format, and populated it representing their own systems. Those individual utility PE-LOSs, and the analysis are included in Appendices A through C of this TM.

The PE-LOS goals for the three utilities turned out to be very similar. A proposed Regional PE-LOS is presented later in this TM.

Elements that LOS Goals Should Address

Performance goals should address:

1. Water quantity
2. Water quality
3. Location of delivery
4. Time frame for achieving the first three

Water quantity can be expressed in terms of normal demands – e.g., Average Annual Demand (AAD) or Average Winter Demand (AWD). Water quality can be quantified in terms of meeting Safe Drinking Water Act requirements. The time frame can be addressed in terms of percent of customers being served.

Goals should be risk based, where risk is a function of likelihood of occurrence, likelihood of failure, and consequence of failure. The higher the risk, the more stringent the goals should be. For example, goals might be more stringent for an earthquake that has a high probability of impact for a function that is critical in achieving the goals (e.g. water treatment). Earthquake probability of occurrence is often stated as a probability within 50 years, an average life for infrastructure: 50 years is sometimes considered to be the average life of a building, 20 years the average life of mechanical equipment, and 100 years the average life of buried pipe. Probabilities of 10 percent, and 2 percent within 50 years are often selected. The associated return period for these events is 475 years (often rounded to 500) and 2,475 years (often rounded to 2,500) respectively. A 10 percent in 50-year event is often referred to as a “design basis” or probable earthquake, and a 2 percent in 50-year event is often referred to as a “maximum” or “maximum probable” earthquake.

LOS goals can be stated in terms of expected performance/outage time to the end user category or of the system-wide functionality. They are sometimes stated to consider such needs as water for drinking and public health, fire suppression, and resumption of commercial and industrial operations within the community. Various organizations and utilities have developed LOS Goals as described in the following section. Still other organizations have developed codes, standards and guidelines to address performance of individual system components. They are presented in the subsequent section.

Guidelines for Establishing Post-Earthquake LOS Goals

Post-earthquake LOS goals should be established only after careful and detailed understanding of the following information:

1. Expected system damage following an earthquake
2. Time to restore service to customers
3. Number of customers facing water outages, including the duration of the outages
4. Economic impact from customer outages
5. Cost to upgrade the water system to reduce the impact of customer outages
6. Regulatory requirements

7. Stakeholder input which includes stakeholder expectations, stakeholder risk acceptance, stakeholder willingness to commit resources to reduce risk, and ultimately buy-off by the governing body of the utility.
8. LOS goals established by utilities of similar size and in areas with comparable seismic activity and expert opinion.

3.0 PE-LOS Goal Examples

PE-LOS goals have been used by utilities at least since the 1990s as captured by the American Water Works Association (AWWA), and further developed by a number of utilities along the west coast. Examples are presented below. The Oregon Resilience Plan (ORP) addressing the Cascadia Subduction Zone earthquake, was developed focusing on top down planning where societal needs were identified, associated with buildings where essential services are provided, and infrastructure identified that is required to deliver those services. The ORP provides some guidance for PE-LOS goals for water supply. Subsequently, the National Institute of Standards and Technology further developed that methodology for multi-hazard applications. Both are further described below.

AWWA Guidance

In 1994, AWWA published *Minimizing Earthquake Damage, a Guide for Water Utilities* (Ballantyne 1994) which provided some LOS guidance (Table 1). This table was based on work Ballantyne had done with several utilities in the Pacific Northwest.

Table 1. Post-Earthquake System Performance Policy Objectives. (From *Minimizing Earthquake Damage, a Guide for Water Utilities*, (Ballantyne, 1994)

Service Category and Order of Priority	Operating Basis Earthquake (50% chance of occurring in 50 years; 72-year return period)	Design Basis Earthquake (10% chance of occurring in 50 years; 475-year return period)
Performance Objectives		
Pipelines	Incidental failures affecting <1% of system; repaired within 24 hours	Failures resulting in service loss of up to 30% of area; repaired within 7 days.
Facilities	Continuous power service. Minor, easily repairable damage to pump stations and reservoirs.	Power out for 72 hours. Minor damage to 70 percent of pump stations, tanks, reservoirs, and impoundments; all remaining operable. Significant damage to 30 percent making them inoperable.
Life Safety	Minimal life-safety risk	Minimal life-safety risk
Fire suppression	Available in all areas	Available from 70 percent of sources or reservoirs after valving off limited areas of damage.
Critical service, Drinking water and public heath, Domestic, commercial, and industrial supply, Property damage	Continuous full service to all areas at winter demand rates. Maintain good water quality	Service to 70 percent of service area at 70 percent of winter flows: potable water made available at centralized locations, both within 72 hours. Boil-water order may be required. No outside use of water. Full service to all but a few areas within 7 days at winter demand rates. Full service to all within 1 month at winter demand rates.
Irrigation	Full service to all areas at summer demand rates within 7 days.	Full service to all within 6 months at summer demand rates.

Water Utility Examples

Various water utilities have developed their own PE-LOS performance goals. Others have seismic projects underway, with the intent of developing PE-LOS goals as follows:

- Portland Water Bureau, Oregon – Nearing completion of their system to determine its expected performance in accordance with the ORP. There is an expectation that they will adopt the ORP recommendations depending on the gaps identified between the expected performance of their existing system and the ORP recommendations, and the resulting mitigation costs.
- Tualatin Valley Water District (TVWD), Beaverton, Oregon – Staff have tentatively adopted the ORP recommendations. TVWD is developing a Water System Master Plan to address those recommendations.
- San Francisco Public Utilities Commission (SFPUC), California - Developed performance standards for system level service after earthquakes. There are short-term (24 hours) and long term (30 days) levels of service that SFPUC plans and designs for. The basic level service criteria are based on delivering winter day demand (low demand for the year) of 215 million gallons per day (MGD) within 24 hours after a major earthquake. A 90 percent confidence level is to be achieved in meeting this goal, which includes delivering at least 70 percent of the winter demand water to SFPUC wholesale customers. It is assumed that no significant repairs are performed in the first 24 hours after a major earthquake. The long-term performance criteria are based on making temporary repairs to restore average daily demand of 300 million gallons per day (MGD) to wholesale customers. It is the intent that all water be disinfected as a minimum, but this objective may be waived for emergency purposes.
- East Bay Municipal Utility District, Oakland, California. Refer to Table 2.
- Santa Clara Valley Water District (SCVWD), San Jose, California – SCVWD is a wholesale provider. The goal is to provide service at winter demand within one week following an M7.8 earthquake on the San Andreas Fault. This earthquake has a 372-year return period. They are working with their retail providers to determine the most effective approach to meet their LOS goals.

Table 2. East Bay Municipal Utility District, Service Level Goals (G&E Engineering, 1994)

Category	Probable Earthquake	Maximum Earthquake
General	Minimal secondary damage and risk to the public	Minimal secondary damage and risk to the public
	Limit extensive damage to system facilities	Limit extensive damage to system facilities
	All water introduced into the distribution system minimally disinfected, using Orinda & Walnut Creek treatment plants	All water introduced into the distribution system minimally disinfected
	All water introduced into the distribution system fully treated	All water introduced into the distribution system fully treated
Fire Service	Sufficient portable pumps to provide limited fire service in all areas	Sufficient portable pumps to provide limited fire service in all high-risk areas
	All areas have minimal fire service (one reliable pumping plant and reservoir)	All areas have minimal fire service (one reliable pumping plant and reservoir)
	High risk areas have improved fire service (all facilities reliable, minimum fire reserves)	High risk areas have improved fire service (all facilities reliable, minimum fire reserves)
	Service to all hydrants within 20 days	Service to all hydrants within 100 days
Hospitals and Disaster Collection Centers	Minimum service to affected area within 1 day (water available via backbone distribution system near each facility)	Minimum service via distribution system or truck within 3 days
	Impaired service to affected area within 3 days (water available via distribution system to each facility, possibly at reduced pressures)	Minimum service within 10 days (water available via backbone distribution system near each facility)
Domestic Users	Potable water via distribution system or truck within 1 day	Impaired service within 30 days (water available via distribution system to each facility, possibly at reduced pressures)
	Impaired service to affected area within 3 days (where available via distribution system to each domestic user, possibly at reduced pressures)	Potable water at central locations for pickup within 3 days. Minimum service to 70% of customers within 10 days
Commercial, Industrial and other Users	Impaired service to affected area within 3 days (water available via distribution system to each commercial or industrial user, possibly at reduced pressures)	Potable water at central locations for pick up within 1 week. Minimum service to 70% of customers within 10 days. Impaired service to 90% of customers within 30 days

Oregon Resilience Plan

In recent years, planners have reached out to utility stakeholders and customers to get a better understanding of their needs. In November 2012, the Washington State Seismic Safety Committee, Emergency Management Council published *Resilient Washington State, A Framework for Minimizing Loss and Improving Statewide Recovery after an Earthquake*. In February 2013, the Oregon Seismic Policy Advisory Committee (OSSPAC) delivered The ORP (OSSPAC, 2013) to the 77th State Legislative Assembly. Both of these documents had broad based involvement from community stakeholders from across their respective states. Both reports evaluated the state of their existing infrastructure systems and developed earthquake performance goals for each of these systems. The ORP went into significantly greater detail and is used herein.

The ORP recommended performance goals for a post-Cascadia Subduction Zone earthquake in the Portland metropolitan area and the Willamette Valley (i.e., the I-5 corridor) are shown in Table 3. Table 3 also shows the expected performance of water systems in their current state. It was the intent that these goals be achieved within 50 years. The Oregon Legislature has not acted on these proposed goals.

Table 3. Oregon Resilience Plan Performance Goals and Current State of Water System Functions following a Cascadia Subduction Zone Earthquake in the Willamette Valley. (OSSPAC, 2013)

System Function	Event Occurs	0-24 hours	1-3 days	3-7 days	1-2 weeks	2-4 weeks	1-3 months	3-6 months	6-12 months
Potable water availalble at supply source		▲	●		◆			X	
Main transmission faciliites, pipes, pump stations and reservoirs operational		◆					X		
Water supply to critical facilities available		●	◆				X		
Water for fire suppression at key supply points		◆		X					
Water for fire suppression at fire hydrants				▲	●	◆			X
Water available at community distribution centers/points			●	◆	X				
Distribution system operational			▲	●	◆				X

Legend

Desired time to restore component to 80-90% operational	◆
Desired time to restore component to 50-60% operational	●
Desired time to restore component to 20-30% operational	▲
Current state (90% operational)	X

NIST Community Resilience Guide for Buildings and Infrastructure

The National Institute for Standards and Technology (NIST) further developed the methodology with in-depth background applicable to multiple hazards.

Supporting infrastructure systems. Building clusters require service from supporting infrastructure systems to be functional. In the short term, temporary solutions may be used to restore service, such as emergency generators or portable water supplies. Communities are encouraged to set functionality levels shown in ***Figure 3*** for recovery of infrastructure systems so they support the building cluster recovery. The focus is on system performance in terms of the percentage of capacity provided at the 30%, 60%, and 90% milestones for the various building clusters. Consideration should be given to redundancies inherent in each infrastructure system and the consequence of the outage.

Figure 3: National Disaster Recovery Framework (NDRF) Recovery Continuum (FEMA 2014)

Table 4 (NIST Table 3-1) Sample Assignment of Building Clusters to Recovery Phases

Recovery Phase	Building Clusters
1. Short Term	**Critical Facilities**
	• Disaster Debris and Recycling Centers • Emergency Operations Centers • Hospitals and Essential healthcare facilities • Police and Fire Stations
	Emergency Housing
	• Animal Shelters • Banking Facilities (location known by community) • Food Distribution Centers • Emergency Shelter for Emergency Response and Recovery Workers • Faith and Community-Based Organizations • Gas Stations (location known by community) • Nursing Homes, Transitional Housing • Public Shelters • Residential Shelter-in-Place
2. Intermediate	**Housing/Neighborhoods/Business**
	• Buildings or Space for Social Services (e.g., Child Services) and Prosecution Activities • Daycare Centers • Essential City Services Facilities • Houses of Worship • Local Businesses • Local Grocery Stores (location known by community) • Medical Provider Offices • Neighborhood Retail Stores • Residential Housing • Schools
3. Long Term	**Community Recovery**
	• Commercial and Industrial Businesses • Non-Emergency City Services • Resilient Landscape Repair, Redesign, Reconstruction, and Repairs to Domestic Environment

Table 5. (NIST Table 3-2) Functionality Levels for Building Clusters

Category	Performance Level
30% functional	Minimum number needed to initiate the activities assigned to the cluster
60% functional	Minimum number needed to initiate usual operations
90% functional	Minimum number needed to declare cluster is operating at normal capacity

Table 6. (NIST Table 9-17) Riverbend USA summary Resilience Table of Performance Goals for Design Earthquake

Functional Category: Cluster	Overall Recovery Time for Hazard and Level Listed Expected Hazard Level								
	Phase 1 – Short-Term			Phase 2 – Intermediate			Phase 3 – Long-Term		
	Days	Days	Days	Wks	Wks	Wks	Mos	Mos	Mos
	0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Critical Facilities									
Buildings	90%							X	
Transportation		90%	X						
Energy		90%	X						
Water			90%		X				
Wastewater				90%				X	
Communication	90%			X					
Emergency Housing									
Buildings				90%					X
Transportation			90%	X					
Energy			90%	X					
Water			90%		X				
Wastewater				90%				X	
Communication				90%	X				
Housing/Neighborhoods									
Buildings						90%			X
Transportation			90%	X					
Energy			90%	X					
Water				90%				X	
Wastewater					90%			X	
Communication				90%			X		
Community Recovery									
Buildings								90%	X
Transportation				90%	X				
Energy			90%	X					
Water				90%				X	
Wastewater							90%	X	
Communication				90%			X		

Legend:

X = Current state of the system

Table 7. (NIST Table 9-14) Riverbend, USA Water Infrastructure Goals for Expected (500-year return) Earthquake

Water Infrastructure	(4) Support Needed	Overall Recovery Time for Hazard and Level Listed Expected Hazard Level								
		Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
		Days			Wks			Mos		
		0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Source										
Raw or source water and terminal reservoirs	R, S			90%						
Raw water conveyance (pump stations and piping to WTP)	R, S				90%				X	
Potable water at supply (WTP, wells, impoundment)	R, S	30%		60%	90%			X		
Water for fire suppression at key supply points (to promote redundancy)	R, S	90%			X					
Transmission (including Booster Stations)										
Backbone transmission facilities (pipelines, pump stations, and tanks)	R, S	90%					X			
Control Systems										
SCADA or other control systems	R, S	30%		60%	90%		X			
Distribution										
Critical Facilities										
Wholesale Users (other communities, rural water districts)	R, S		60%	90%			X			
Hospitals, EOC, Police Station, Fire Stations	R, S		60%	90%			X			
Emergency Housing										
Emergency Shelters	R, S		60%	90%			X			
Housing/Neighborhoods										
Drink water available at community distribution centers	R, S			60%	90%					
Water for fire suppression at fire hydrants	R, S				90%				X	
Community Recovery Infrastructure										
All other clusters	R, S			30%	90%				X	

Legend:

R = Regional; S = State; X = Current state of the system.

Water Supply Forum Utilities' Seismic Analysis and Recommended LOS Structure

During the several years prior to initiation of, and during the Water Supply Forum Regional Water Supply Resiliency Project, Everett, SPU and TPU conducted seismic vulnerability assessments of their own systems. Each of these utilities developed their own internal PE-LOS tables for both the CSZ and crustal earthquakes. The Cascade Water Alliance is primarily dependent on obtaining their water supply from SPU, and so agreed to be grouped with the SPU PE-LOS proposed tables. A summary of those utility assessments is included in Appendices A through C.

Relying heavily on the formats developed in the ORP and NIST, draft formats and draft PE-LOS goals were developed for two levels of earthquakes, a CSZ scenario, and a crustal fault scenario. The CSZ is common to all of the utilities. Everett and Seattle each have a crustal fault passing through or near their

cities with similar return periods (about 2,500 years or 2 percent in 50 years). The South Whidbey Island Fault (SWIF) is near Everett, and the Seattle Fault passes through Seattle. The Tacoma Fault passes through Tacoma but has a longer return period. As a result, Tacoma chose to use probabilistic ground motions with a 2,500-year return period, similar to the other two utilities.

The draft PE-LOS goal tables for the CSZ and crustal earthquakes were distributed to the three utilities. Each was asked to modify the tables to represent their own utility. The PE-LOS tables for each utility are included in Appendices A through C along with supporting information.

4.0 Proposed Regional PE-LOS Goals

Using the PE-LOS tables submitted for the two utilities, and observation of the third, the lowest common PE-LOS levels were selected for the CSZ and the crustal earthquake to be used for regional PE-LOS performance goals. The PE-LOS for the crustal event was adjusted accordingly. Refer to Tables 8 and 9 below.

The utilities assumed that immediately following the event, a limited quantity of water suitable for customer use would remain in storage reservoirs, and that water would remain potable until it ran out and needed to be refilled from the transmission system. There could be short-term disruptions/damage to water treatment plants and/or transmission pipelines that could result in inadequate treatment or contamination of water available to refill the terminal reservoirs. If inadequately treated or contaminated water entered the terminal reservoirs, the stored water would need to be considered non-potable. Each utility is expected to make the determination as to which reservoirs are potable and which are non-potable, in the hours/days following the earthquake.

The utilities' conclusion was that it would take 14 days to restore potable water in the transmission system and terminal storage, primarily because of the concern about damage in the transmission system. Once pressure is lost, the system water quality should be considered non-potable.

For the transmission/terminal storage system, there was consensus that it would take at least 3 days to restore 50 percent of AWD and up to 14 days for full AWD, again related to the concern about some damage to the transmission pipelines.

The goal for the major regional essential facilities is that 50% of AWD should be available from the transmission/supply immediately after the event. This would come from either existing or alternative reliable supplies, and a dedicated resilient pipeline connecting the supply to the essential facilities. Utilities have different approaches for achieving this goal, but the results are similar.

The Forum chose to use a 50 year planning horizon for PE-LOS goals because capital improvement projects have high costs that require the projects to be phased in over time. Incremental improvements over a long period of time will avoid substantial spikes in costs that would require large increases in water rates. The PE-LOS goals will assist Forum members and other utilities to identify capital projects for strategic, phased development.

The Forum recognizes that more rapid attainment of these goals is desirable, but will be subject to availability of funding. Each utility can establish the appropriate pace of improvements aimed at achieving the PE-LOS goals, consistent with priorities in their respective service areas. As a follow-up to this Resiliency Project, each regional utility should identify interim milestones for capital improvements that will advance towards achievement of the 50-year goals.

Table 8. PE-LOS Goals for a CSZ Earthquake Scenario. (Attain within 50 years and establish interim milestones leading to these goals.)

System Component	Service Provided		Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply transmission system, provide local distribution source (wells), fill tank trucks.	Quantity	Storage	Storage	50% AWD[1]	50% AWD[1]	50% AWD[1]	AAD
		Quality	Non-Potable[4]	Non-Potable[4]	Non-Potable[5]	Non-Potable[5]	Potable	Potable
Transmission to End Points[2]	Supply terminal reservoir, wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment etc.)		50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	AWD	AAD
Transmission/Supply to Major Regional Essential Services[3]	Serve essential customers (e.g. hospitals).		50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	AWD
Backbone	Supply special seismic resistant lines to essential customers, service to community distribution points, provide fire suppression along backbone.		Individual utility decision					
System Storage	Support backbone and local distribution		limited water from storage for fire, drinking		Individual utility decision			
Distribution	Service to individual customers - residential, business, industrial. Water to fire hydrants for fire suppression.		Individual utility decision					

AWD = Average Winter Demand; AAD = Average Annual Demand

Notes:

1. Percentages represent the estimated percent of total delivery. Not all areas will be feasible to serve within the first month.

2. Transmission to End Points includes one or more transmission pipelines providing the noted level of service connecting the supplies to and including the first terminal reservoirs downstream from each supply. At the utility's discretion, additional transmission pipeline segments and reservoirs can be included in this criterion.

3. Transmission/Supply to Major Regional Essential Services includes a supply, and transmission line supplying water to hospitals designated as essential by the utility. The supply and transmission may be dedicated to supply to essential services and be different than the supply and transmission system serving the overall utility service area. Additional facilities in addition to hospitals such as nursing homes, may be designated by the utility.

4. Water supply and water held in terminal reservoir are expected to be potable immediately after the event. However, there could be short-term disruptions/damage to water

treatment plants and/or transmission pipelines that could compromise potability of water in the terminal reservoir within 24 hours following the event.

5. Disruptions/damage to the transmission pipelines could result in contamination of water coming from treatment plants or into terminal reservoirs until repairs can be made and normal operations are resumed.

Table 9. PE-LOS Goals for a Crustal Fault Earthquake Scenario. (Attain within 50 years and establish interim milestones leading to these goals)

System Component	Service Provided		Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply transmission system, provide local distribution source (wells), fill tank trucks.	Quantity	Storage	Storage	50% AWD	50% AWD[1]	50% AWD[1]	AWD
		Quality	Non-Potable[4]	Non-Potable[4]	Non-Potable[5]	Non-Potable[5]	Non-Potable[5]	Potable
Transmission to End Points[2]	Supply terminal reservoir, wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment etc.)		25% AWD[1]	25% AWD[1]	25% AWD[1]	50% AWD[1]	50% AWD[1]	AWD
Transmission/Supply to Major Regional Essential Services[3]	Serve essential customers (e.g. hospitals).		50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	AWD
Backbone	Supply special seismic resistant lines to essential customers, service to community distribution points, provide fire suppression along backbone.		Individual utility decision					
System Storage	Support backbone and local distribution		limited water from storage for fire, drinking		Individual utility decision			
Distribution	Service to individual customers - residential, business, industrial. Water to fire hydrants for fire suppression.		Individual utility decision					

AWD = Average Winter Demand

Notes:

1. Percentages represent the estimated percent of total delivery points supplied. Not all areas will be feasible to serve within the first month.

2. Transmission to End Point includes one or more transmission mains providing the noted level of service connecting the supplies to and including the first terminal reservoirs downstream from each supply. At the utility's discretion, additional transmission pipeline segments and reservoirs can be included in this criterion.

3. Transmission/Supply to Major Regional Essential Services includes a supply, and transmission line supplying water to hospitals designated as essential by the utility. The supply

and transmission may be dedicated to supply to essential services and be different than the supply and transmission system serving the overall utility service area. Additional facilities in addition to hospitals such as nursing homes, may be designated by the utility.
4. Water supply and water held in terminal reservoir are expected to be potable immediately after the event. However, there could be short-term disruptions/damage to water treatment plants and/or transmission pipelines that could compromise potability of water in the terminal reservoir within 24 hours following the event.
5. Disruptions/damage to the transmission pipelines could result in contamination of water coming from treatment plants or into terminal reservoir until repairs can be made and normal operations are resumed.

5.0 References

Ballantyne, Donald 1994, *Minimizing Earthquake Damage, a Guide for Water Utilities*, prepared for the American Water Works Association, Denver, Colorado.

G&E Engineering, 1994, East Bay Municipal Utility District Seismic Evaluation Program Final Report, Oakland, California.

Oregon Seismic Policy Advisory Committee (OSSPAC), 2013, *The Oregon Resilience Plan (ORP),* prepared for the 77th State Legislative Assembly, Salem, Oregon. February 2013.

National Institute of Standards and Technology (NIST), 2015, *Community Resilience Planning Guide for Buildings and Infrastructure Systems*, 99% Draft, Gaithersburg, Maryland. April 21, 2015.

APPENDIX A - EVERETT

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Everett - Post-Earthquake Water System Level of Service Goals - 11/7/17

50-year planning horizon		**Total**
Moderate funding level:	Everett Tables 4.1 ($1.3) & 4.2 ($38M)+ items 6 and 7 from Table 4.3 ($3.5M)	**$42.8M**
Aggressive funding level:	Everett Tables 4.1 ($1.3) & 4.2 ($38M)+ Table 4.3 ($48M)	**$87.3M**

Expected performance for aggressive funding level shown in tables below)
Funding for Tables 4.1 & 4.2 included in CIP through 2027 (10 years)
Funding for Table 4.3 (aggressive) is generally agreed on but final decision made over time

Cascadia Subduction Zone Earthquake, 50-year horizon, Aggressive Funding

System Component	Service Provided	Immediatley After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply Transmission System, Provide local distribution source (wells), fill tank trucks						
	Quanity	Storage	50% AWD	50% AWD	AWD	AWD	AAD
	Quality	Potable	Potable	Potable	Potable	Potable	Potable
Transmission to End Points	Supply Terminal Reservoir, Supply wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment, etc)			50% AWD	AWD	AWD	AAD
Transmission/Supply to Major Regional Essential Services	Serve hospitals - Dependent on hospital funding construction: 1) pipe from reservoir, 2) pipe from well, 3) well on site	AWD	AWD	AWD	AWD	AWD	AAD

Crustal Earthquake (SWIF), , 50-year horizon, Aggressive Funding

System Component	Service Provided	Immediatley After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply Transmission System, Provide local distribution source (wells), fill tank trucks						
	Quanity	Storage	Storage	50% AWD	50% AWD	AWD	AWD
	Quality	Potable	Potable	Potable	Potable	Potable	Potable
Transmission to End Points	Supply Terminal Reservoir, Supply wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment, etc)				50% AWD	50% AWD	AWD
Transmission/Supply to Major Regional Essential Services	Serve hospitals - Dependent on hospital funding construction: 1) pipe from reservoir, 2) pipe from well, 3) well on site	AWD	AWD	AWD	AWD	AWD	AAD

Table 4.1 IP - 1 Mitigation Measures (from Carollo Engineers Water System Seismic Assessment Report for the City of Everett, June 2012**)**

Mitigation Measure	Estimated Cost	
	Natural Hazards	**Anthropogenic Hazards**
1. Table Top Hazard Response Planning Exercise	$50,000	
2. Emergency Response Plan Update & Training	$85,000	
3. Assessment and Purchase of Parts & Materials for Warehousing	$115,000	
4. Mutual Aid and/or Contractor Agreements	$250,000	
5. Critical Customer Restoration Planning & Preparedness	$25,000	
6. Post event Hydraulic Capability Analysis	$50,000	
7. Phase 2 Vulnerability Assessment	$200,000	
8. System Earthquake Risk Assessment (SERA Modeling)	$60,000	
9. Water Filtration Plant Volcanic Ash Treatment Study	$150,000	
10. Operational Security Procedures & Awareness Training (SAT)		$25,000
11. Water Filtration Plant:		
a. Operations Building Anchor & Restraint Upgrades	$3,000	
b. Emergency Generators Battery Restraints	$1,000	
Subtotals	**$989,000**	**$25,000**
Contingency (≈30%)	**$297,000**	**$7,000**
Totals	**$1,286,000**	**$32,000**
Total		**$1,318,000**

Table from Carollo Engineers Water System Seismic Assessment Report for the City of Everett, June 2012

Table 4.2 IP – 2 Mitigation Measures (Carollo Engineers Water System Seismic Assessment Report, City of Everett, June 2012)

	Mitigation Measure	Estimated Cost	
		Natural	Anthropogenic
Supply	1. Sultan River Diversion Landslide Mitigation Upgrades	$1,555,000	
	2. Chaplain Reservoir and South Dam:		
	a. Dam Seismic Upgrades	$1,000,000	
	b. CCTV Monitoring		$50,000
	3. Water Filtration Plant Upgrades:		
	a. Intake Structure Bridge Seismic Upgrades	$150,000	
	b. Existing Flocculation Basin (warehousing parts) & new pile supported	$15,000	
	c. Operations Building Seismic Upgrades	$552,000	
	d. Filter Building Seismic Upgrades	$1,004,000	
	e. East Clearwell Seismic Upgrades	$400,000	
	f. Finished Water Pump Station 2 Seismic Upgrades	$300,000	
	g. Buried Pipes Seismic Upgrades	$3,000,000	
	h. Hazmat Building (Previous Chlorine Facility)	$70,000	
	i. Perimeter Protection Improvements		$250,000
	j. Access Control System Improvements		$15,000
	k. Internal Plant CCTV Monitoring System		$70,000
Transmission	4. Tunnels 2 & 3 and Portals 3 through 5:		
	a. Seismic Upgrades to Portland 3 Building	$4,000	
	b. CCTV Monitoring and IR lighting at Penstocks		$15,000
	c. Upgrade Existing CCTV at Portals		$9,000
	5. Panther Creek Screening House - CCTV Monitoring System		$25,000
	6. Cavalaro Pressure Sustaining Facility – Perimeter Fencing and CCTV Monitoring System		$25,000
	7. Transmission Line 3:		
	a. Long-sleeve Mechanical Couplings	$180,000	
	b. Elevated Sections Seismic Support Upgrades	$150,000	
	d. Buried Pipe Sections Seismic Upgrades for Lateral Spreading	$2,304,000	
	8. Transmission Line 5:		
	a. Long-sleeve Mechanical Couplings	$120,000	
	b. Elevated Section Seismic Upgrades (Additional Supports)	$2,310,000	
	c. Buried Pipe Sections Seismic Upgrades for Lateral Spreading	$4, 896,000	
	9. Reservoir 3:		
	a. Inlet and Outlet Pipe Protection from Roof Collapse	$40,000	
	b. Seismic Upgrades	$1,500,000	
	c. Perimeter Protection Improvements		$100,000
	d. CCTV Monitoring System		$50,000
	Subtotal	**$14,654,000**	**$609,000**
	Contingency (≈30%)	**$4,396,000**	**$183,000**
	Engineering, Legal, Permits, Administrative, etc. (≈45%)	**$8,573,000**	**$356,000**
	Totals	**$27,623,000**	**$1,148,000**
	Total		**$28,771,000**

Table 4.3 IP – 3 Mitigation Measures (from Carollo Engineers Water System Seismic Assessment Report for the City of Everett, June 2012)

Mitigation Measure	Estimated Cost	
	Natural Hazards	**Anthropogenic Hazards**
1. Water Filtration Plant New Pile-Supported Flocculation Basin	$2,400,000	
2. Transmission Line 2 Seismic Upgrades		
a. Elevated Section Seismic Upgrades (Additional Supports)	$3,150,000	
b. Buried Pipe Sections Seismic Upgrades for Lateral Spreading	$2,304,000	
3. ~~Transmission Line 4 Seismic Upgrades~~		
~~a. Elevated Section Seismic Upgrades (Additional Supports)~~	~~$6,300,000~~	
~~b. Buried Pipe Sections Seismic Upgrades for Lateral Spreading~~	~~$4,368,000~~	
4. ~~Transmission Lines 2, 3, and 4 CCTV Monitoring System~~		~~$400,000~~
5. ~~Transmission Line 5 CCTV Monitoring System~~		~~$400,000~~
6. Reservoir 2 Seismic Upgrades (Slope Stabilization)	$2,000,000	
7. Everett Way Pump Station Seismic Upgrades	$1,500	
8. Reservoir 6N Seismic Upgrades (Wire Re-wrap)	$2,000,000	
9. Reservoir 6S Seismic Upgrades (Wire Re-wrap)	$2,000,000	
Subtotals	**$24,523,500**	**$800,000**
Contingency (≈30%)	**$7,357,000**	**$240,000**
Engineering, Legal, Permits, Administrative, etc. (≈45%)	**$14,346,000**	**$468,000**
Totals	**$46,227,000**	**$1,508,000**
Total		**$47,735,000**

Table 4.4 Post Event Water System Flow Rate Requirements (from Carollo Engineers Water System Seismic Assessment Report for the City of Everett, June 2012)

Service Category	Level of Service Goal	Required Restoration Periods		Approximate Flow Rate Required [(1)] (MGD)		
		Probable Event	Maximum Event	Demand Criteria	2012	2050
City of Everett Customers	1	2 to 2.5 days	3 to 5 days	Low Winter	7	15
	2	2 to 3 days	7 to 10 days	Low Winter	7	15
	3	20 to 30 days	60 to 120 days	Avg. Winter	10	20
Wholesale Customers (have their own storage)	1	2 to 3 days	5 to 10 days	Low Winter	32	70
	2	2 to 5 days	10 to 20 days	Low Winter	32	70
	3	20 to 30 days	60 to 120 days	Avg. Winter	45	100
Industrial (Line 4)	1	3 to 5 days	10 to 15 days	Impaired Capacity	15	15
	2	7 to 10 days	60 to 90 days	Commercial Production	30	30

Notes:

Flow rates are based on information in *City of Everett, 2007 Comprehensive Water Plan, Chapter 3 Planning Data and Demand,* HDR & City of Everett, November 21, 2007

During performance of the study, the industrial customer requiring the current and projected future flows closed. Accordingly, in the future, the industrial flows noted in this table may not be required.

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APPENDIX B - SEATTLE PUBLIC UTILITIES

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Seattle Public Utilities (DRAFT)
Post-Earthquake Water System Level of Service Goals
Cascadia Subduction Zone Earthquake Scenario
50-year Horizon
Aggressive Funding

System Component	Service Provided		Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply transmission system, provide local distribution source (wells), fill tank trucks.	Quantity	Storage	50% AWD	50% AWD	50% AWD	AWD	AAD
		Quality	Non-Potable	Non-Potable	Non-Potable	Potable	Potable	Potable
Transmission to End Points	Supply terminal reservoir, wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment etc.)				50% AWD	50% AWD	AWD	AAD
Transmission/Supply to Major Regional Essential Services	Serve essential customers (e.g. hospitals).		50% AWD	50% AWD	50% AWD	50% AWD	AWD	AAD
Backbone	Supply special seismic resistant lines to essential customers, service to community distribution points, provide fire suppression along backbone.		Individual utility decision					
System Storage	Support backbone and local distribution		limited water from storage for fire, drinking		Individual utility decision			
Distribution	Service to individual customers - residential, business, industrial. Water to fire hydrants for fire suppression.		Individual utility decision					

Note: Percentages represent the estimated percent of total delivery points supplied.

Seattle Public Utilities (DRAFT)
Post-Earthquake Water System Level of Service Goals
Seattle Fault Earthquake Scenario
50-year Horizon

Aggressive Funding

System Component	Service Provided		Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply transmission system, provide local distribution source (wells), fill tank trucks.	Quantity	Storage	Storage	50% AWD	50% AWD	50% AWD	AWD
		Quality	Non-Potable	Non-Potable	Non-Potable	Non-Potable	Potable	Potable
Transmission to End Points	Supply terminal reservoir, wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment etc.)					50% AWD	50% AWD	AWD
Transmission/Supply to Major Regional Essential Services	Serve essential customers (e.g. hospitals).		50% AWD	50% AWD	50% AWD	50% AWD	50% AWD	AWD
Backbone	Supply special seismic resistant lines to essential customers, service to community distribution points, provide fire suppression along backbone.		Individual utility decision					
System Storage	Support backbone and local distribution		limited water from storage for fire, drinking		Individual utility decision			
Distribution	Service to individual customers - residential, business, industrial. Water to fire hydrants for fire suppression.		Individual utility decision					

Note: Percentages represent the estimated percent of total delivery points supplied.

Seattle Public Utilities (SPU) has almost completed a 2-year drinking water system seismic study. The study expands on a previous seismic vulnerability assessment that occurred in the 1990s. Since 1990, SPU has been working on seismic readiness and addressing issues identified in the 1990s study. The goal of the new study is to incorporate current understandings of seismic risk into long-term resilience planning for the water system. The new study:

1. Identifies and defines seismic hazards
2. Assesses seismic vulnerability of vertical facilities and pipelines
3. Models the water system's response to and recovery from catastrophic earthquakes, including Cascadia Subduction Zone and Seattle Fault Zone earthquakes.
4. Includes performance goals, mitigation recommendations and cost estimates
5. Analyzes the sizing of treated water storage in post-earthquake recovery
6. Establishes new design standards for new buried pipelines

The study results are being vetted internally. When they are ready for release, the details will be shared with the Water Supply Forum for follow-on phases of the Resiliency work.

Study recommendations will include:

- Improve emergency preparedness and response planning (stockpile repair material, provide emergency drinking water after earthquake).
- Ensure there is adequate water storage to provide emergency water for fire fighting and other customer needs.
- Use isolation and control strategies to manage the rate of loss of stored water.
- Upgrade existing facilities to meet current seismic requirements and ensure that all new facilities are built to meet those requirements.
- Continue to improve the seismic reliability of critical transmission lines through seismic upgrades.
- Require and install earthquake-resistant pipe in seismic hazard areas.
- Implement new seismic design standards for new buried pipelines going forward.

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APPENDIX C – TACOMA PUBLIC UTILITIES

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Tacoma Public Utilities (DRAFT)
Cascadia Subduction Zone Earthquake Scenario
50-year horizon,
Aggressive Funding

System Component	Service Provided	Immed-iately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply Transmission System, provide local distribution source (wells), fill tank trucks						
	Quantity	Storage	50%AWD	50% AWD	50% AWD	AWD	AAD
	Quality	Non-Potable	Non-Potable	Non-Potable	Potable	Potable	Potable
Transmission to End Points	Supply Terminal Reservoir, Supply wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment, etc.)			50% AWD	50% AWD	AWD	AAD
Transmission/Supply to Major Regional Essential Services	Serve essential customers (e.g. hospitals) Major Regional Essential Services	50% AWD	50% AWD	50% AWD	50% AWD	AWD	AAD

Tacoma Public Utilities (DRAFT)
2,475 Probabilistic Ground Motion Earthquake Scenario
50-year horizon
Aggressive Funding

System Component	Service Provided	Immed-iately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply Transmission System, Provide local distribution source (wells), fill tank trucks						
	Quantity	Storage	Storage	50%AWD	50% AWD	50% AWD	AWD
	Quality	Non-Potable	Non-Potable	Non-Potable	Non-Potable	Potable	Potable
Transmission to End Points	Supply Terminal Reservoir, Supply wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment, etc.)				50% AWD	50% AWD	AWD
Transmission/Supply to Major Regional Essential Services	Serve essential customers (e.g. hospitals) Major Regional Essential Services	50% AWD	50% AWD	50% AWD	50% AWD	50% AWD	AWD

Cost Summary

Water Supply

Sequence	CSZ Amount	CF Amount
First	$4,620,000	$5,860,000
Second	$0	$1,000,000
Third	$0	$0
Subtotal	$4,620,000	$6,860,000
N/A	$0	$250,000
Total	**$4,620,000**	**$7,110,000**

Transmission to Supply

Sequence	CSZ Amount	CF Amount
First	$9,480,200	$11,080,200
Second	$160,090,000	$166,315,000
Third	$24,050,000	$27,050,000
Subtotal	$193,620,200	$204,445,200
N/A	$261,800,000	$262,000,000
Total	**$455,420,200**	**$466,445,200**

Transmission to Essential Services

Sequence	CSZ Amount	CF Amount
First	$276,200	$276,200
Second	$0	$0
Third	$0	$0
Subtotal	$276,200	$276,200
N/A	$0	$0
Total	**$276,200**	**$276,200**

Totals

Sequence	CSZ Amount	CF Amount
First	$14,376,400	$17,216,400
Second	$160,090,000	$167,315,000
Third	$24,050,000	$27,050,000
Subtotal	**$198,516,400**	**$211,581,400**
N/A	$261,800,000	$262,250,000
Total	**$460,316,400**	**$473,831,400**

Post Event Level of Service Memo

5/8/2018

Michael Washington, P.E., and Seth Doull, P.E.

Purpose

Develop a list of mitigation projects and associated costs that could be implemented over a 50-year period that would help Tacoma Water meet the proposed aggressive Post Earthquake Level of Service (PE-LOS) Service Goals for a Cascadia Subduction Zone (CSZ) earthquake scenario and a 2,475-year return period Crustal (CF) Earthquake Scenario.

This is intended to be a high level effort that will spark discussion and begin the process of refinement, with respect to the goals in the PE-LOS chart below, mitigation alternatives and timeline. The PE-LOS is in alignment with goals established by the Water Suppliers Forum. The distribution system was not reviewed as part of this effort. As such, this report does not include figures for hardening strategic portions of the distribution system.

Key Findings

Based on higher level analysis, both the CSZ and CF event will cause widespread damage and impacts to Tacoma Water's infrastructure. Much of what is known about these seismic events was not known at the time the system was designed and constructed. We expect many of our facilities to be heavily damaged and several will be completely inoperable following such an event. As such, substantial investment will be required in order to ensure that the system can deliver the PE-LOS identified in this document. It is important to also point out, this effort focused on our primary, critical and essential infrastructure. There are many secondary and redundant facilities that are not accounted for in this document as they are not required to meet the PE-LOS. It is expected that they may be significantly damaged as well.

One interesting note is our large transmission pipelines (P1, P2, P4 and P5) are expected to suffer substantial damage following both the CSZ and TFC scenarios. The failures are driven primarily by a combination of the installation of concrete pipe in poor soils (eg liquefiable) and some exposure to pipelines installed on steep slopes. Reservoirs, on the other hand, are expected to perform rather well in the CSZ scenario (suffering mostly "slight" damage), but are expected to experience "moderate" or greater damage in the CF scenario, which, based on preliminary findings of the 2017/18 seismic analysis study of Hood Street Reservoir, may likely cost on the order of one million dollars to seismically retrofit. This accounts for the majority of the cost difference between meeting to CSZ PE-LOS versus the CF PE-LOS.

We believe that Tacoma Water will need to invest approximately:

$199M to $460M to meet the PE-LOS for the CSZ scenario (depending on replacement of P1 and P4)

$212M to $474M to meet the PE-LOS for the CF scenario (depending on replacement of P1 and P4)

Meeting the PE-LOS for the CF would, by default, also meet the CSZ scenario PE-LOS.

It is important to point out that these figures do not include costs for upgrading the distribution system (other than a couple key backbone mains identified in this memo).

Narratives around the effort and included in the remainder of this document. Please note that cost estimates that were developed are high level costs based on engineering judgment and are intended to act as a placeholder until further analysis can be done to refine the cost.

Key Terms Used in the Excel Document

The following key terms were used as a part of the calculations needed to complete the analysis.

Average Winter Demand (AWD) is approximately 46MGD; does not include our Regional Water Supply Partner Demands

Average Annual Demand (AAD) in MGD is approximately 55 MGD; does not include our Regional Water Supply Partner Demands

Regional Water Supply Partner Avg Annual Demand is approximately 15 MGD (14.3MGD; taken from 2017 Midnight Report)

Regional Water Supply Partner Avg Winter Demand is approximately 11 MGD (11.7MGD; taken from 2017 Midnight Report)

Damage States:

- Slight/Minor- Operable following event. 100% capacity immediately following event
- Moderate- Sustained damage, safe and operable during repair. 50% capacity immediately following earthquake
- Extensive- inoperable but repairable; may be yellow or red tagged (which could limit access) 0% capacity immediately following earthquake
- Complete- unrepairable, collapsed, etc. 0% capacity immediately following earthquake

Actions

- Proactive Replacement- Replace the asset ahead of time with one that can remain operational following a specific seismic event scenario (either the CSZ or the CF)
- Seismic Upgrade- Harden the existing asset by reinforcing it, adding supporting brackets, improving foundations, etc. so that they asset can remain operational following a specific seismic event scenario (either the CSZ or the CF)
- Repair- The asset is expected to be damaged during a specific seismic event scenario. Asset will be repaired if damaged during a specific seismic scenario
- No Action Needed

Sequence (order in which projects could be prioritized)

- First- Need to have to meet level of service within the first week following the event
- Second- Need to have to meet level of service at 2 weeks following the event
- Third- Need in place to meet level of service at 1 month following the event
- N/A - Not necessarily needed to meet level of service

It is important to point out that, basically speaking, projects that are “Second” need to have the “First” projects in place in order to be operational. “Third” would require “Second” projects in place, etc.

Important Assumptions/Resources

The 2015 All-Hazards Vulnerability Assessment (VA) was an important resource for understanding our system performance in the CSZ and CF earthquake scenarios. Unfortunately, there were some technical nuances that prevented us from being able to completely cross walk over the analysis from the VA. These are summarized below:

VA models the Crustal Event using the Tacoma Fault which has a return period of approximately 4,500 years. The model then shows larger damages and more impacts than would be expected from a 2,475-year return period crustal fault scenario.

Building performance in the VA model is based on a quick site inspection and cursory review of building construction documents to understand basic construction techniques used. A detailed structural analysis with calculations for each facility damaged was not part of this effort. As such, following detailed, site specific analysis and modeling, it is highly likely that expected damaged due to a particular earthquake scenario may be smaller or larger than this study estimates.

The Outage Model in the VA provides high level damage states for facilities and quantifies impacts in terms of outages and people, not on capacity/demand. Additionally, the model "splits the baby" for outages if redundant facilities are both out of service, versus attributing them to a critical path scenario based on our response plan. Repair times are included/documented for each facility in the VA.

Facility, Distribution Piping and Transmission Main performance is quantified. Facilities have damage states labeled as Slight/Minor, Moderate, Extensive and Complete. Distribution Pipes (evaluated by pressure zone) and pipelines (evaluated by pipeline) use a fragility model to identify number of breaks and leaks.

PE-LOS

The Water Supply Forum, in conjunction with HDR and Don Ballantyne, developed the PE-LOS framework for both the CSZ and the CF scenarios. The three main categories for the level of service are: Water Supply, Transmission to End Points, and Transmission/Supply to Major Regional Essential Services. These will be further explained below.

Based on the analysis efforts, Tacoma Water worked to establish what a possible PE-LOS could be given the infrastructure investment contained in this document.

Tacoma Water

Cascadia Subduction Zone Earthquake, 50-yr horizon, Aggressive Funding

System Component	Service Provided	Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply Transmission System, Provide local distribution source (wells), fill tank trucks						
	Quantity	Storage	50% AWD	50% AWD	50% AWD	AWD	AAD
	Quality	Potable	Non-Potable	Non-Potable	Potable	Potable	Potable
Transmission to End Points	Supply Terminal Reservoir, Supply wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment, etc)			50% AWD	50% AWD	AWD	AAD
Transmission/Supply to Major Regional Ess	Serve essential customers (e.g. hospitals) Major Regional Essential Services	50% AWD	50% AWD	50% AWD	50% AWD	AWD	AAD

Figure 1: Tacoma Water PE-LOS Chart for CSZ

Tacoma Water

2,475-yr Return Period Crustal Event Earthquake, 50-yr horizon, Aggressive Funding

System Component	Service Provided	Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply Transmission System, Provide local distribution source (wells), fill tank trucks						
	Quantity	Storage	Storage	50% AWD	50% AWD	50% AWD	AWD
	Quality	Potable	Non-Potable	Non-Potable	Potable	Potable	Potable
Transmission to End Points	Supply Terminal Reservoir, Supply wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment, etc)				50% AWD	50% AWD	AWD
Transmission/Supply to Major Regional Ess	Serve essential customers (e.g. hospitals) Major Regional Essential Services	50% AWD	50% AWD	50% AWD	50% AWD	50% AWD	AWD

Figure 2: Tacoma Water PE-LOS Chart for CF

As part of this effort, facilities and their associated performance (damage states) for the CSZ and CF scenarios were compiled for each of the PE-LOS categories, as well as the action that Tacoma Water should take regarding them (proactive replacement, seismic upgrade, repair after the event or no action needed) and the associated costs for doing so.

The costs estimates that were developed are high level costs based on engineering judgement and are intended to act as a placeholder until further analysis and study can be done to refine the cost. These numbers are useful for planning and discussion. Upon further study, they will change.

Furthermore, the efforts were identified with respect to sequence as first, second, third and N/A. First means that the infrastructure is needed in order meet the level of service within the first week following

the event. Second means that the infrastructure is needed in order meet the level of service 2 weeks following the event. Third means that the infrastructure is needed in order meet the level of service 1 month following the event. N/A was reserved if the ifrastructure is not technically needed to meet the level of service.

Furthermore, a strategy for developing a PE-LOS needs to be formulated and signed off by our governing board to be able to move PE-LOS projects forward.

Water Supply

The Water Supply category for the PE-LOS tables is defined as the source and the ability to properly treat the source to provide potable water.

PE-LOS in terms of MGD Needed

		Immediately After	24 hours	3 days	7 Days	14 Days	1 Month
CSZ	Storage	50% AWD	50% AWD	50% AWD	AWD	AAD
mgd		23	23	23	46	55
CF	Storage	Storage	50% AWD	50% AWD	50% AWD	AWD
mgd			23	23	23	46

Figure 3: PE-LOS Table (in MGD) for Water Supply Category

For Tacoma Water, the focus will be on South Tacoma Well Field System primarily because it is the closest source to the city and it is expected that damage will occur to both Pipelines 1 and 5, thus limiting the GRFF from being a reliable source immediately following a CSZ or CF event.

This entire system needs to be functional following a seismic event in order for Tacoma Water to have potable water available in the days following the event.

In order to meet this need, it is believed that seismic retrofitting of several South Tacoma Wells, Hood Street Hypo chlorination building, Hood Street Reservoir will suffice to make this possible.

The Hood Street Groundwater Treatment Facility will also require a seismic retrofit, but has been classified as low priority as it is not needed for potable water.

It is possible that the Wells line between South Tacoma Pump Station and Hood Street Reservoir may require a repair. We have elected to go keep the pipeline as is and repair a leak if one should occur based on the ~$34M replacement cost.

Transmission to End Points

The Transmission to End Points category for the PE-LOS tables is defined as the ability to move water from the source to terminal reservoirs in Tacoma Water's system.

PE-LOS in terms of MGD Needed

	Immediately After	24 hours	3 days	7 Days	14 Days	1 Month
CSZ			50% AWD	50% AWD	AWD	AAD
mgd			23	23	46	55
CF				50% AWD	50% AWD	AWD
mgd				23	23	46

Figure 4: PE-LOS Table (in MGD) for Transmission to End Points Category

This was taken to be understood that we need to provide water to our major backbone facilities, which are outlined below. Essentially, we have to be able to deliver South Tacoma Wells water through our system within 3 days following the CSZ. We will have 7 days to do so following the CF. Source Water from the GRFF needs to be available by day 14 following the CSZ and 1 month following the CF.

Partner and Wholesale connections were not evaluated or specifically addressed as part of this effort.

To aid in the evaluation of Tacoma Water's system, the system was broken apart into xx sections, with each section being rather unique in how it was fed or served.

1) Pipeline 5

   This pipeline will be our main source of water from the GRFF. Pipeline 1 is devastated in both the CSZ and CF scenarios (20 to 30 breaks and leaks per scenario). This pipeline is also needed to supply water to Indian Hills Reservoir (if Lakehaven emergency intertie is not operable). Portland Avenue Reservoir becomes an important distribution point.

2) Pipeline 2 and McMillin

   This system allows Tacoma Water to move groundwater from the South Tacoma Wells back to McMillin using Pipeline 2 and the Hood Street Pump Station.

3) North End

   This includes the infrastructure Hood Street Reservoir (including the Hood Street Pump Station and Hypo Building) to J Street via Pipelines 2 and 4. North End Transmission Main to the North End Reservoir and the 21st Street intertie from J Street to Alaska Street Reservoir. This system allows water to move throughout the City, refill our large reservoirs and ultimately provide water to the distribution system.

4) 810 Zone

   This system will require water to move to McMillin from in town and the ability to move water via Pipeline 1 and the Fennel Creek Pump Station on the East side of the Puyallup River Valley so that it can be pumped to the 198th Street E Pump Station. This water will then be transmitted via the distribution system to Prairie Ridge Tank. There is also a large reliance on the Prairie Ridge Springs site, as it is the only local source of water available in the 810 zone. Assumes Tacoma Water can activate intertie with Bonney Lake to feed the 705 zone.

5) Indian Hills

   This system uses the Lakehaven Emergency Intertie or Pipeline 5, 356th Street Pump Station and distribution main to move water to the Indian Hills Reservoirs

6) Sunrise

   This system requires McMillin Pump Station No. 2, the steel discharge piping and some distribution main to move water to the Sunrise Tank.

7) West End

   This system will move water by way of South Tacoma Pump Station, the West End Transmission Main and 40th Street Trunk Main to University Place. UP Tanks and distribution main to get to Trunk Main were not included in this discussion.

8) Pipeline 1
   This system from the Headworks to 198th Street E Pump Station will be significantly affected by both scenarios. It is envisioned that this would be the last pipeline to be mitigated given its redundancy with Pipeline 5 (and the ability to move water to the 810 zone from in town). Effects will largely be isolated to customers in Cumberland and Palmer.

9) Pipeline 4
This is a lower priority main given its redundancy with Pipeline 2. Effects will be largely isolated to customers in the Woodland 581 and 426 pressure zones. Additionally, it makes it difficult to access the GPL wells.

Transmission/Supply to Major Regional Essential Services

PE-LOS in terms of MGD Needed

	Immediately After	24 hours	3 days	7 Days	14 Days	1 Month
CSZ	50% AWD	50% AWD	50% AWD	50% AWD	AWD	AAD
mgd	23	23	23	23	46	55
CF	50% AWD	50% AWD	50% AWD	50% AWD	50% AWD	AWD
mgd	23	23	23	23	23	46

Figure 5: PE-LOS Table (in MGD) for Transmission to Major Regional Essential Services Category

This effort will be limited to looking at the major medical providers in our service area: Tacoma General, St. Joseph, and Allenmore hospitals. Other important customers such as kidney dialysis and nursing homes will not be included in this specific effort.

These three facilities are located centrally in Tacoma in the Central District and Hilltop respectively and rely on the Hood Street Facilities and In-Town wells for water immediately following the a CSZ or CF seismic scenario. The three facilities can really be grouped into two for analysis:

1) Tacoma General and St. Joes

These two hospitals are part of the three hospitals (the other being Madigan Army Hospital at JBLM) that comprise the Tacoma Trauma Center. The Tacoma Trauma Center is solely responsible for providing Level II trauma for the South Sound.

They will rely on direct feed from Pipeline 2 or 4 coming out of Hood Street and require Hood Street Pump Station to be operational (as well as the South Tacoma Wells system).

St. Joseph lies half a block directly north of the Pipeline 2/Pipeline 4 connection at the J Street Control Building. The hospital is readily served by existing 12-inch DI pipe in good soils. Money was allocated for possible valve upgrades so that this pipe can be isolated with a high degree of confidence from the rest of the system to ensure water service can be maintained.

Tacoma General Hospital lies 1.2 miles directly north of the Pipeline 2/Pipeline 4 connection at the J Street Control Building. The hospital relies on the same existing 12-inch DI pipe to get water to the 8-inch DI pipe in S I Street. Money was allocated for possible valve upgrades so that this pipe can be isolated with a high degree of confidence from the rest of the system to ensure water service can be maintained. Additionally, money was allocated to upgrade the existing 6-inch CIP in 6th Avenue to allow for a robust tie in between the 8-inch DI in S I Street and the 12-inch DI main in the northern part of MLK.

2) Allenmore

This is a community hospital that provides 24-hour emergency care to the community. It lies a little more than a mile west of the Pipeline 2/Pipeline 4 connection at the J Street Control Building.

This relies on the Alaska Street reservoir and 16-inch CIP pipe in S 19th Street to remain in service (as well as some newer DI pipe in the immediate vicinity of the hospital).

We will need to consider using Alaska Street Reservoir is better than some piping upgrades that would allow us to possible bypass the reservoir (which is expected to be damaged and will require seismic upgrading to remain functional).

Before we make any significant investments, we also need to better understand if these hospitals structures are capable of withstanding the scenario seismic events and the hospitals plans for post-earthquake operations.

Conclusions

Hardening infrastructure to remain operational following the CSZ or CF scenarios is an expensive proposition. It is only recently that the seismicity of our region has become better understood and has resulted in a new understanding of how infrastructure needs to be designed; important considerations that were not available when the majority of our infrastructure was constructed.

The difference in performance of our system in a CSZ or a CF event is evidenced in the first pass at quantifying the costs needed to harden our infrastructure. Transmission Mains are heavily damaged in both scenarios, but it is our reservoirs that make up the bulk of the costs difference between the 2 scenarios. This is an important observation that will need to be taken into account as we prioritize infrastructure upgrades and replacements.

This memo is meant to capture our initial foray into understanding system seismic performance and the improvements that may be necessary for us to remain functional following such an event. However, this is just the beginning. The limited time and resources allocated to this effort will become apparent as we invest money into studying each component in more depth; broad assumptions and conclusions will break down and we will have to rethink/retool our initial thoughts. In the meantime, this will get the conversation and planning/strategy efforts going that are necessary to successfully plan for the future, educate our elected officials and inform our ratepayers and customers about what to expect following a large scale seismic event.

Next Steps

Develop strategy and plan for sharing outcomes of this effort, within Tacoma Water, Tacoma Public Utilities, City of Tacoma, Service Area, the Water Supply Forum and the Puget Sound Region.

Develop plan (including timeline, budget and resources) for projects identified in this document and in the VA. As this effort develops, considerations must be made for understanding the next layer of infrastructure: the distribution backbone system followed by the distribution system itself. Of important note will be an isolation strategy immediately following the seismic event that balances needs for fire fighting/suppression with needs to maintain reservoir levels and system pressure to key facilities and infrastructure.

Prioritize seismic study and improvement work on in town wells and Hood Street facilities.

Develop seismic design recommendations for distribution pipe and transmission mains that can be used for future projects.

Identify pipes that need to be considered for seismic upgrade so that future planning efforts related to infrastructure renewal will know that certain pipes need to meet seismic design requirements.

Begin effort to review Pipeline 2 and identify the sections that will need to be mitigated first. Focus should be on concrete pipe and pipe in liquefiable soils.

Review Pipeline 5 to identify specific locations of anticipated leaks and breaks and develop response plans and identify repair materials.

Develop plan for expanding out to other reservoir facilities identified in this document.

Develop response plan and infrastructure improvement plan to serve the 810 zone east of the Orting Valley.

Build relationship with USGS and encourage additional research related to the Tacoma Fault Crustal Scenario (which is a 4,500-year return period event). This will help with development of design criteria for new and renovated facilities and infrastructure.

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